# SAMPLE POSITIONING SYSTEM TO IMPROVE EDGE MEASUREMENTS

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## PRIORITY INFORMATION

The present application is a continuation application of U.S. Patent Application No. 10/132,959 filed April 26, 2002, STAGE ROTATION SYSTEM TO IMPROVE EDGE MEASUREMENTS, which claims the benefit of U.S. Provisional Application Serial No. 60/298,711 filed June 15, 2001, STAGE ROTATION SYSTEM TO IMPROVE EDGE MEASUREMENTS, which is incorporated herein by reference.

## FIELD OF INVENTION

The present invention relates to a method of making metrology measurements of a semiconductor wafer and, in particular, includes an approach for improving measurements near the edge of the wafer.

## BACKGROUND OF INVENTION

Semiconductor manufacturers are interested in taking measurements at selected points on a wafer from the center out to the edges thereof. In order to obtain accurate measurement, the focal spot of the probe beam must not extend beyond the wafer edge. As can be appreciated, any portion of the beam which extends beyond the wafer's edge will not be reflected resulting in an unexpected reduction in measured intensity which leads to errors in the analysis. In addition, edge effects can cause scattering, also reducing the accuracy of the measurement.

Because of this problem, the metrology device must be configured to limit how close the center of the focal spot can be moved to the edge during a measurement. This restriction is not typically a problem if the probe beam spot is relatively small and circular. However, when the probe beam is large and has an elliptical shape, problems arise. This problem is present with current X-ray reflection measurements and ellipsometry systems, where a focused X-ray beam is directed onto a wafer at a non-normal angle of incidence. For example, U.S. Patent No. 5,619,548 and PCT WO 01/71325, both incorporated herein by

reference describe methods and apparatus for X-ray reflectometry with a focused X-ray beam directed onto a wafer with an angle of incidence in a range between 87.8 and 89.9 degrees from normal. In another example, U.S. Patent No. 5,973,787, also incorporated herein by reference, describes an ellipsometry system with an angle of incidence of an optical beam in the range between 30 and 70 degrees from normal.

As an example, Figure 1 illustrates a probe beam 2 directed onto a wafer 1 at a high angle of incidence $\Phi$ as measured from the normal 12. Although the probe beam itself has a generally circular cross section, the spot 7 on the wafer surface is elliptical, having a short axis W substantially corresponding to the beam diameter and a long axis L which is dependent upon, among other factors, the angle of incidence of the beam on the sample. In particular, for a circular beam, the long axis of the elliptical beam spot is defined by

$$L = d / \cos \Phi \qquad [1]$$

where d is the beam diameter and $\Phi$ is the angle of incidence of the beam. As can be appreciated from equation (1), increasing the angle of incidence of the beam increase the long axis of the ellipse. For a high angle of incidence, such as used in an X-Ray reflectometer, the long axis of the ellipse can be more than five times longer than the short axis. This elliptical beam spot has caused problems when attempting to take measurements close to the edge of a wafer due to the scattering and edge effects mentioned above.

This problem will be discussed with reference to Figure 2. More specifically, in many existing systems, the wafer rests on a movable stage. The stage is used to vary the position of the wafer with respect to the beam spot. For ease of explanation, Figure 2 shows an X-Y coordinate system with the center of the wafer being at $O_x, O_y$. If it is desired to measure at a site near the top center of wafer $(O_x, N_y)$, the stage is moved so the beam spot is located at position "A". As can be seen, the center of the beam spot can be moved quite close to the wafer edge without the edges of the beam extending beyond the wafer edge.

In contrast, if it desired to measure at position $(N_x, O_y)$, which is a similar distance from the wafer's edge as position A, the beam spot would extend at over the edge of the wafer. Accordingly, the center of the beam spot must be moved to position B, which is farther from the edge than position A. Accessing measurement areas on a wafer using only

X, Y linear motions to position an elliptical beam spot means that the area actually accessible for measurement is elliptical in configuration as indicated by ellipse 8 of Fig. 2. (It should be understood that the illustrated dimensions are not drawn to scale, particularly the beam spot which has been greatly enlarged.)

## BRIEF SUMMARY

The subject systems and methods can allow for more uniformity at all measurement sites near the edge of the wafer around the wafer circumference. To achieve this goal, a theta ($\theta$) or rotational stage is used to rotate the wafer so that short axis W of the ellipse is oriented perpendicular to the wafer edge when measurements at sites near the edge are desired.

## BRIEF DESCRIPTION OF THE FIGURES

Fig. 1 shows a simplified perspective view of a probe beam incident upon the wafer at a non-normal angle of incidence.

Fig. 2 shows a schematic top view illustrating the positions of an elliptical spot near the wafer's edge.

Fig. 3 shows a simplified metrology apparatus including an X, Y and theta stage for performing the inventive method.

Fig. 4 shows a schematic top view of a wafer illustrating a measurement at position A.

Fig. 5 shows a schematic top view of the wafer of Figure 4 rotated 90 degrees and illustrating a measurement at position B.

## DETAILED DESCRIPTION

In Figure 3, a metrology apparatus 15 features a linear motion system including an X-stage 19 mounted on top of a Y-stage 21. The X-stage 19 carries a theta stage 17. A

wafer chuck 21 is mounted on top of the theta stage to support wafer 1. The illustrated order of the stacking of the stages should not be viewed as limiting the subject invention.

In accordance with the subject invention, when it is desired to obtain a measurement in close proximity to the wafer edge, the linear stages 19, 21 move the wafer 1 in conjunction with the theta stage 17 such that the short axis W of the beam spot is substantially perpendicular to the wafer edge. As seen in Figure 4, measurement spot A can be measured in the same manner as in the prior art. However, when point B is to be measured, the wafer is rotated 90 degrees to a position as illustrated in Figure 5. In this orientation, elliptical spot 7 can be moved closer to the edge of the wafer as compared to the measurements shown in Figure 2. Using the subject method, the measurement boundary is now circular in shape as illustrated by circle 9 of Figures 4 and 5.

For the most part, the system can be operated in a manner similar to the prior art. More specifically, the X, Y stage can be used to position the wafer with respect to the beam for any sites within the elliptical boundary 8 of Fig. 2. However, when it is desired to measure sites near the wafer edge, the theta stage can be used to rotate the wafer an amount sufficient to align the short axis of the measurement spot to be perpendicular to the edge of the wafer. In this manner, the area of exclusion can be minimized.

As is well known by those skilled in the art, various measurement protocols are designed by users. For example, one protocol might include four edge measurements and a single center measurement ($O_x$, $O_y$). Another protocol might require many more measurements over a wafer surface. It should be understood that the subject invention is broad enough to include these variations. Measurements can be taken in any order. Sites can be accessed using various combinations of X, Y and theta stage adjustments. The subject invention is invoked when it is desired to measure near an edge at a location that would have otherwise not been feasible with the prior art approach.

In a particular example, assignee herein markets an X-ray reflectometer with an X-ray probe beam directed at the sample at a high angle of incidence. The resulting elliptical spot has a short axis of about 2 to 3mm and a long axis of between 5 and 10mm. This spot dimension resulted in an effective edge exclusion varying from the optimum of about 1-2mm ($0_x$, $N_y$ of Figure 2) to the worst case of up to 10mm ($N_x$, $0_y$ of Figure 2). In contrast, using

the method of the subject invention, the edge exclusion around the entire circumference is uniform and reduced to 1 to 2mm.

As noted above, with respect to equation (1), the length of the long axis of the elliptical spot increases as the angle of incidence increases. Thus, the problem of edge exclusion is more severe with high angle of incidence devices such as an X-ray reflectometer.

When using the subject method, the edge exclusion is governed by the length of the short axis and is therefore independent of angle of incidence.

Although the subject method has been described in the context of using a stage with X,Y and theta movements, it may also be possible to implement the invention with other known wafer translation systems. For example, stage systems with smaller footprints such as 1/2X, 1/2Y, theta or R-theta stage combinations might be used. Also, the relative movement can be achieved with some combination of stage movement and measuring optics movement. For example, a rotary stage system can be combined with a linearly moving optics system. Alternatively, a linear stage system can be combined with a rotating optics head to obtain similar results.